ET against Hamamatsu: 1“ hemispherical PMT selection

Ching-Cheng Hsu, Jürgen Hose, Florian Goebel, Agnes Rudert, Olaf Reiman, Razmick Mirzoyan and a few other people

Presented by Razmick Mirzoyan

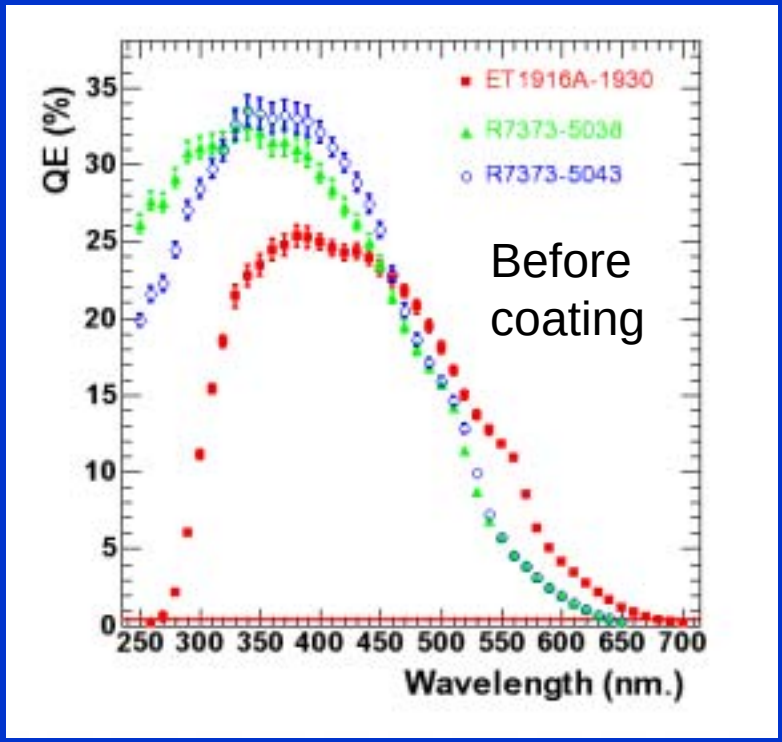
PMTs we have tested

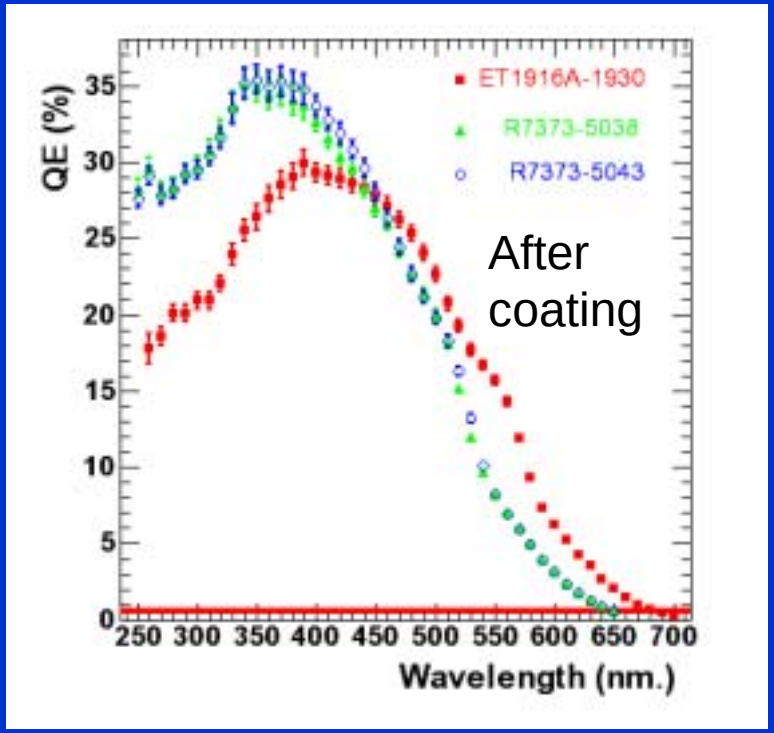
DW Type (x 2): DW 142, DW139
9116WA-10001, 9136-WA-10005
Latest 9: 9116WA-117, 118, 140, 141,
10005, 10006, 10008, 10015, 10014

xc3350, xc3344, xc3348, xc3352
Latest 5: xc3354, xc3353, xc5551, zl7016,
zl7018
10 stage: zl5043

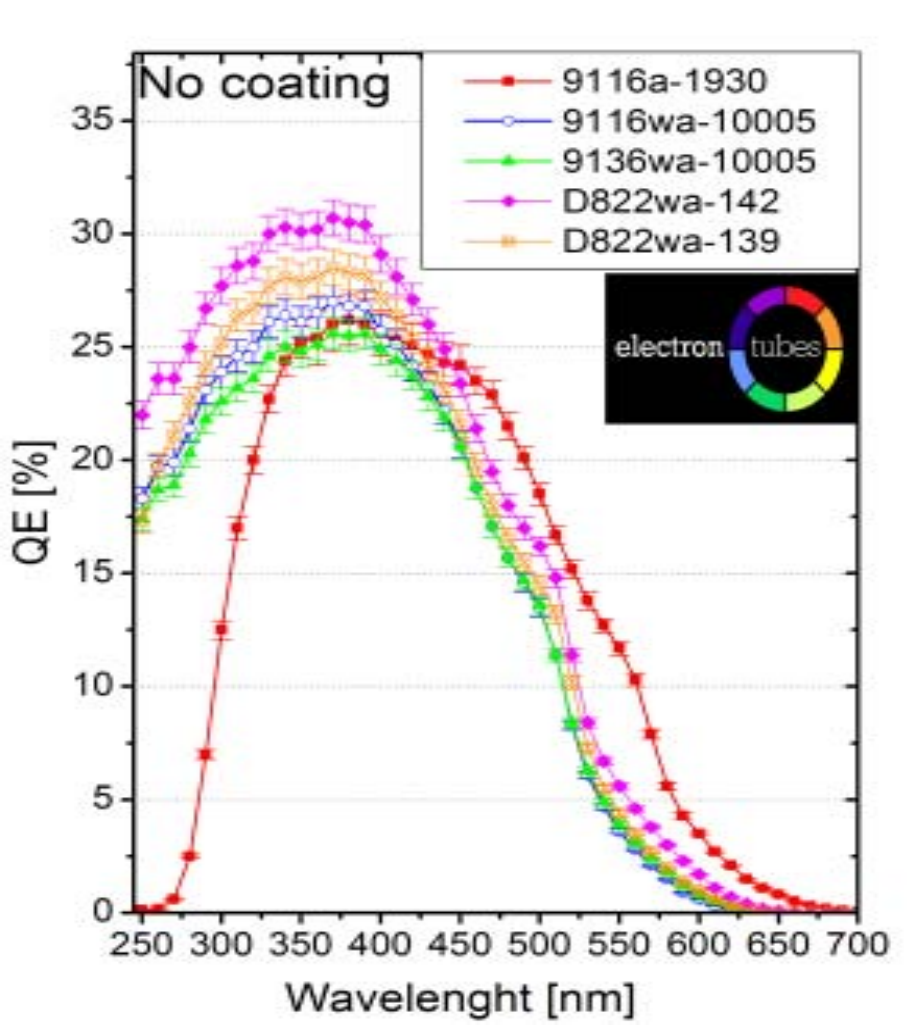
xp040, xp028

The beginning: QE of 3 PMTs (2 *Hamamatsu* + 1 *ET*) before and after coating with milky layer



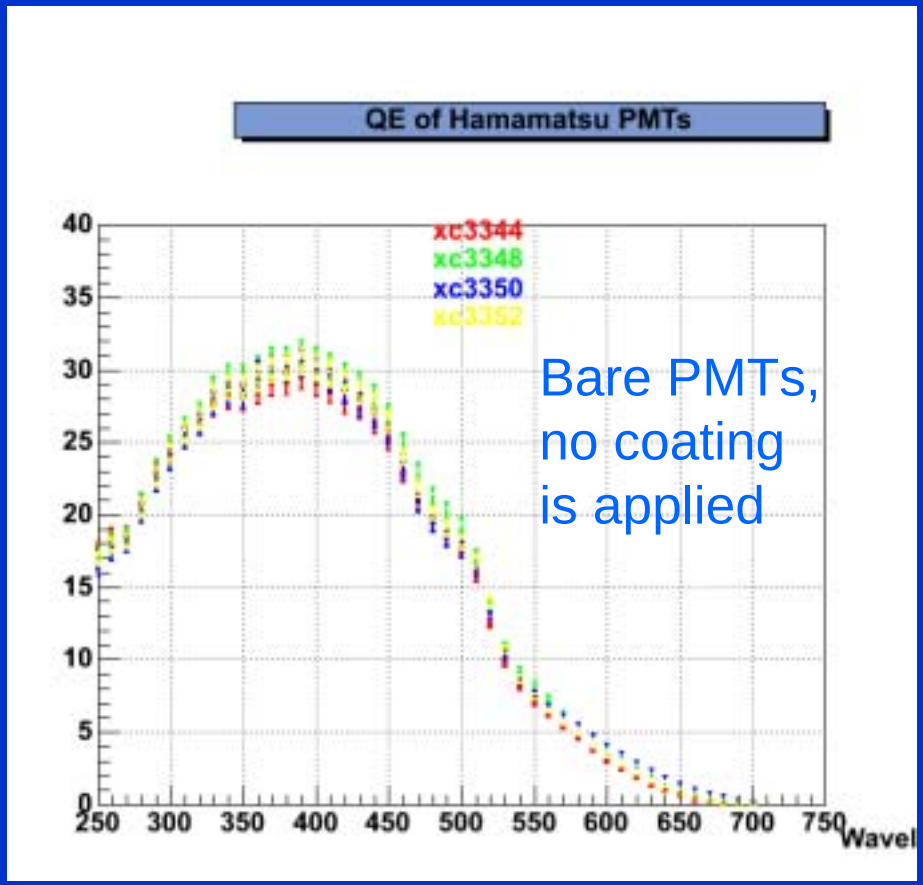


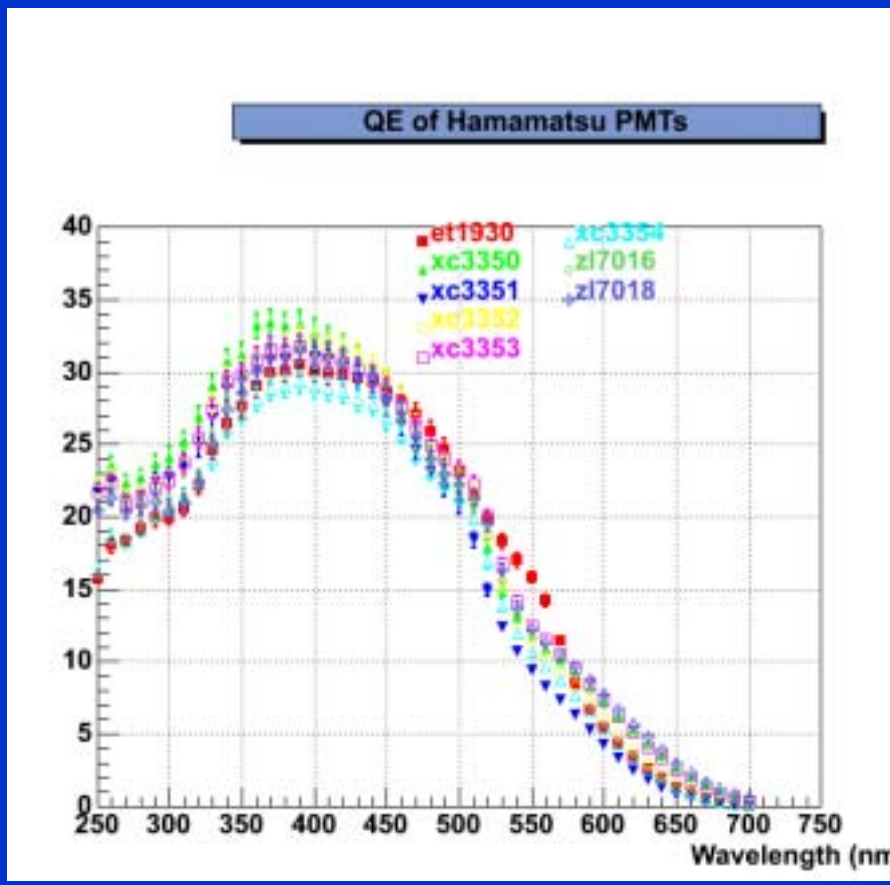
High QE progress of **ET**



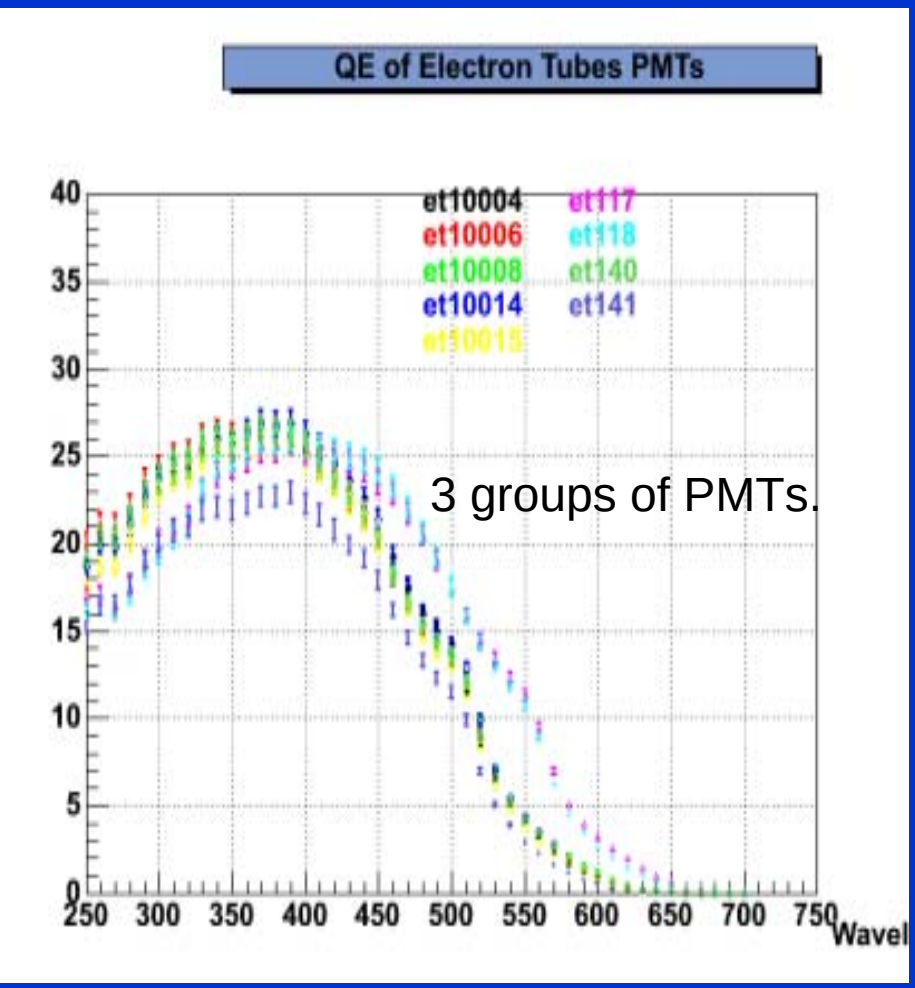
- Tubes/batches show different behaviour
- With increasing peak QE the curves move to the "left" and show lower QE at higher λ.
- => the photo cathode thickness is reduced.
- => Higher interference efficiency (QE) at shorter λ.

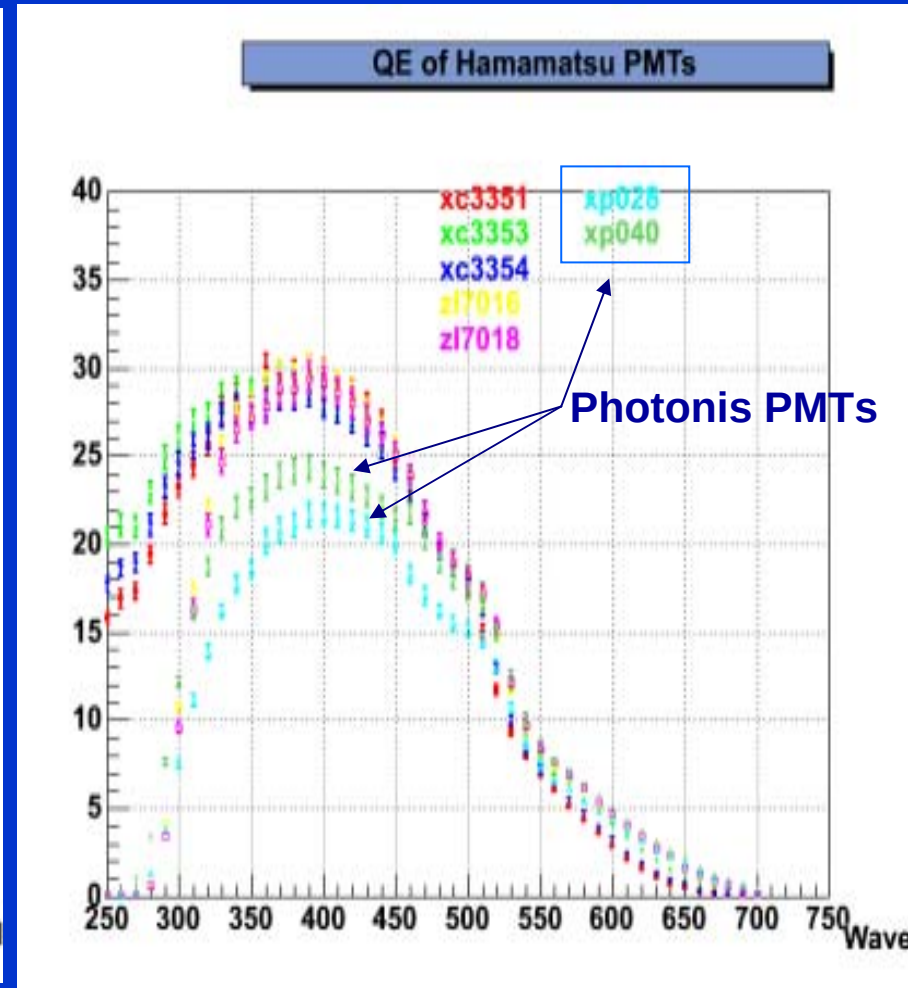
QE of recent **Hamamatsu** PMTs





QE of ET, Hamamatsu and Photonis PMTs

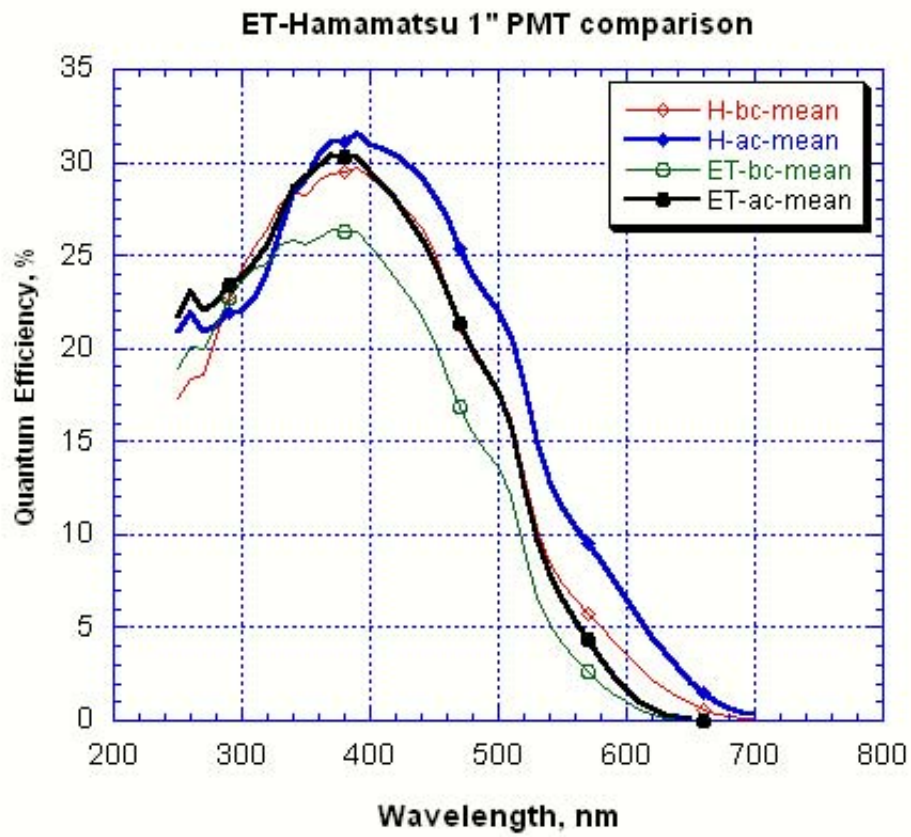




Average representative PMT

- We tested a relatively high representative number of PMTs from both ET and Hamamatsu.
- Beacuse of varying experimental production character many single PMTs show QE curves that largely differ in spectral behavior, so it is not conclusive.
- In the following we present the average character of PMTs. Averaging is done by calculating the arithmetical mean in small spectral bins of 10-20 nm.

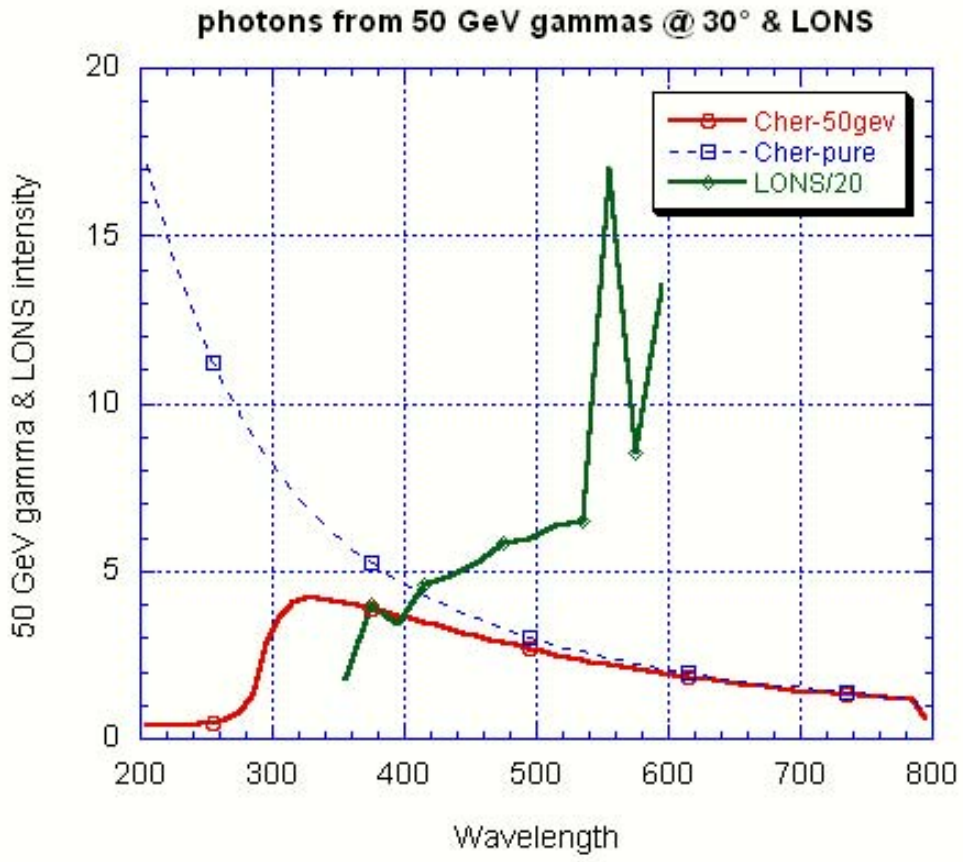
Averaged representative curves of tested PMTs from ET & Hamamatsu



H - stands for Hamamatsu
ET - for Electron Tubes
bc - before coating
ac - after coating

Uncoated Hamamatsu (H-bc-mean) is quite comparable with coate ET (ET-ac-mean)

LONS & Cherenkov photons



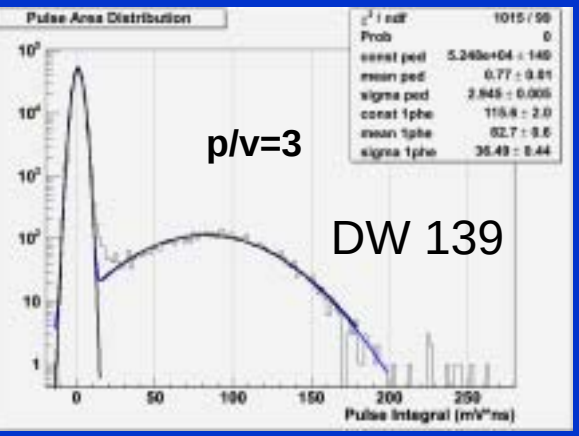
Pratik provided simulations of Cherenkov photons from air Showers of 50 GeV from zenith angles 10°, 20°, 30° & 40°. We agreed to chose 30° as a representative for calculations.

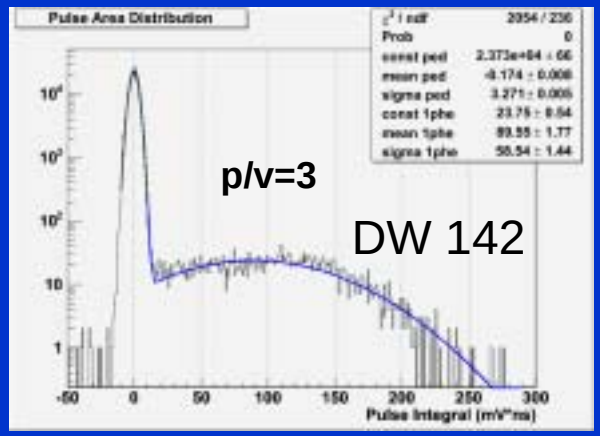
LONS curve I have calculated from the LONS measurements made at La Palma by the ING group (Chris Ben, et. al.,)

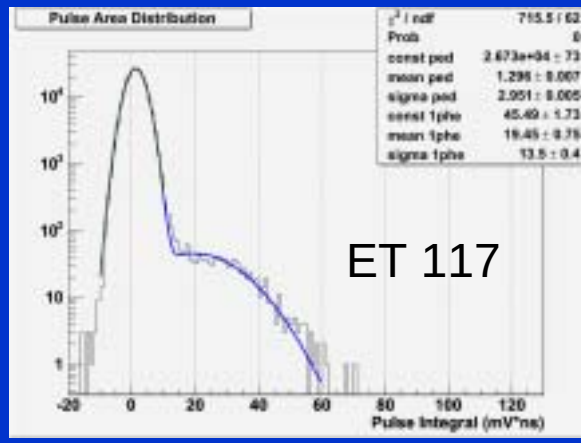
Average QE folded with Cherenkov spectrum and with LONS

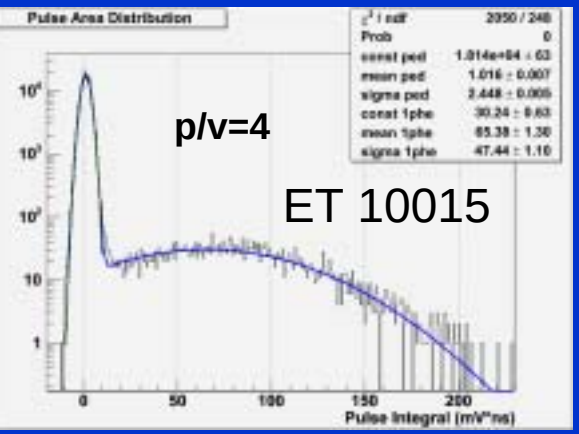
PMT type & <QE>, %	Before coating, fold with Cherenkov	After coating, fold with Cherenkov	Before coating fold with LONS	After coating fold with LONS
Electron Tubes	14.8	17.2 (+ 16 %)	11.3	14.3 (+ 26.5 %)
Hama matsu	17.3	19 (+ 10 %)	14.9	18.4 (+ 23.5 %)

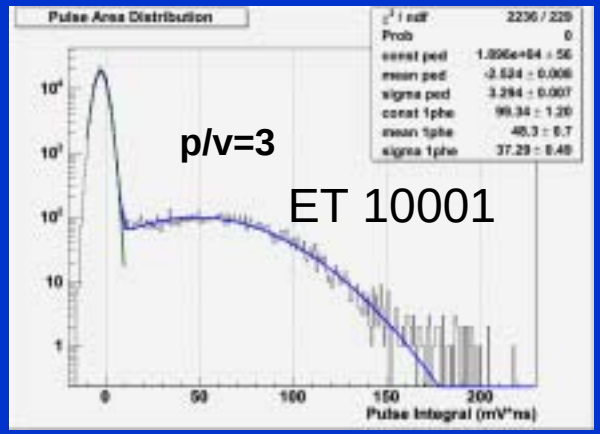
Single ph.e. Spectra: ET

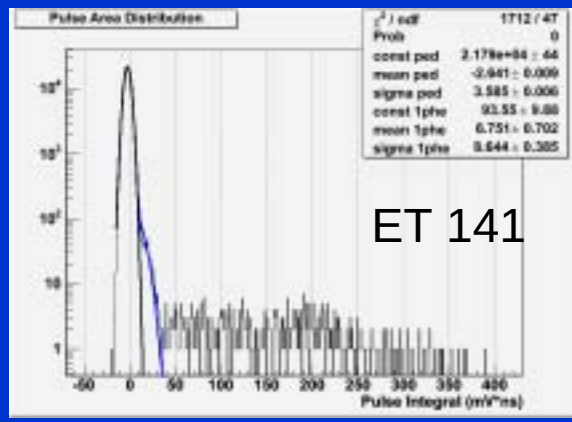




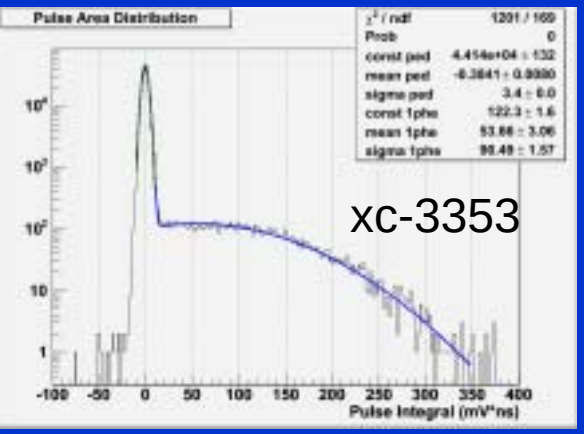


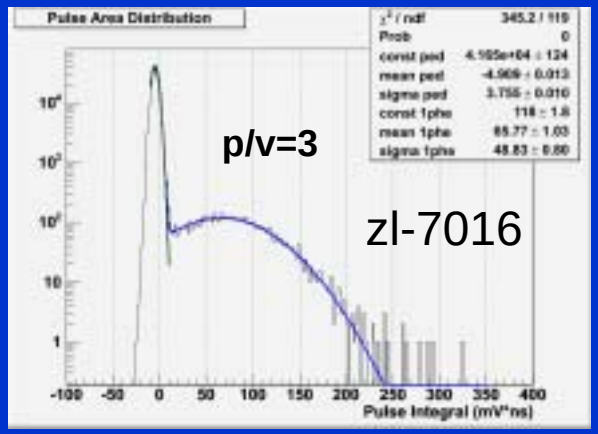


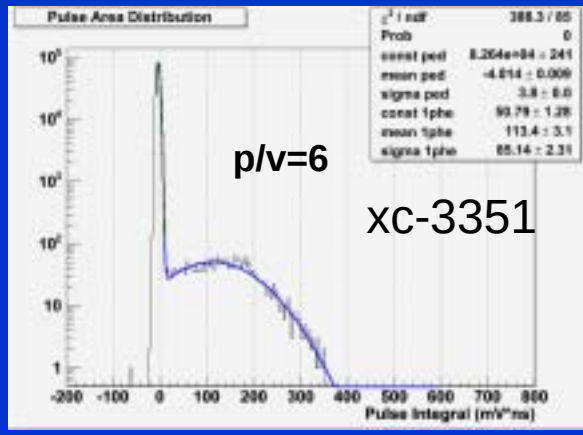


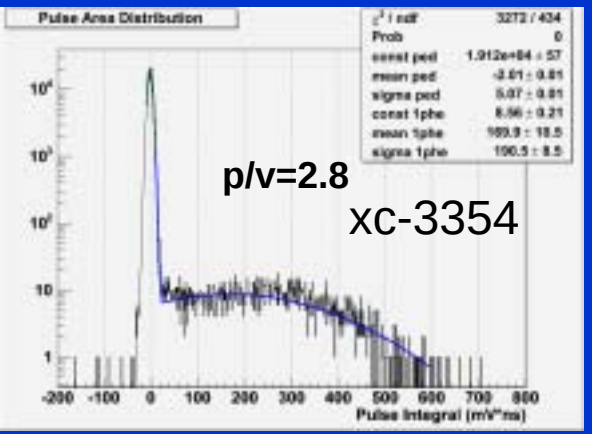


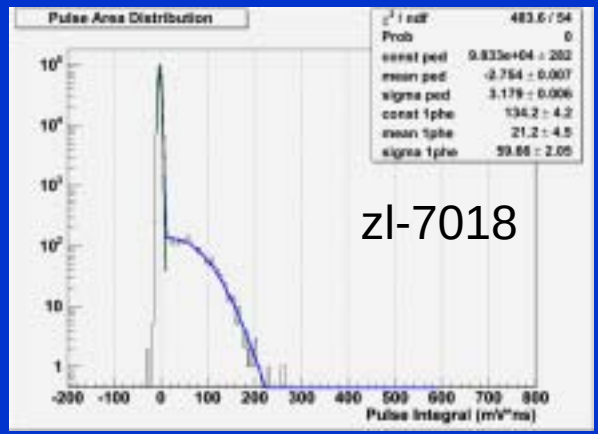
Single ph.e. Spectra: Hamamatsu

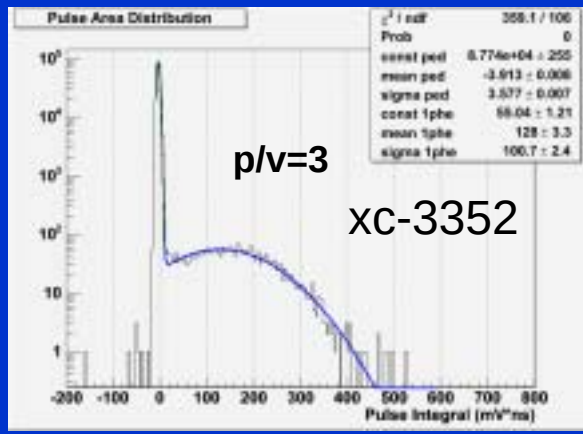












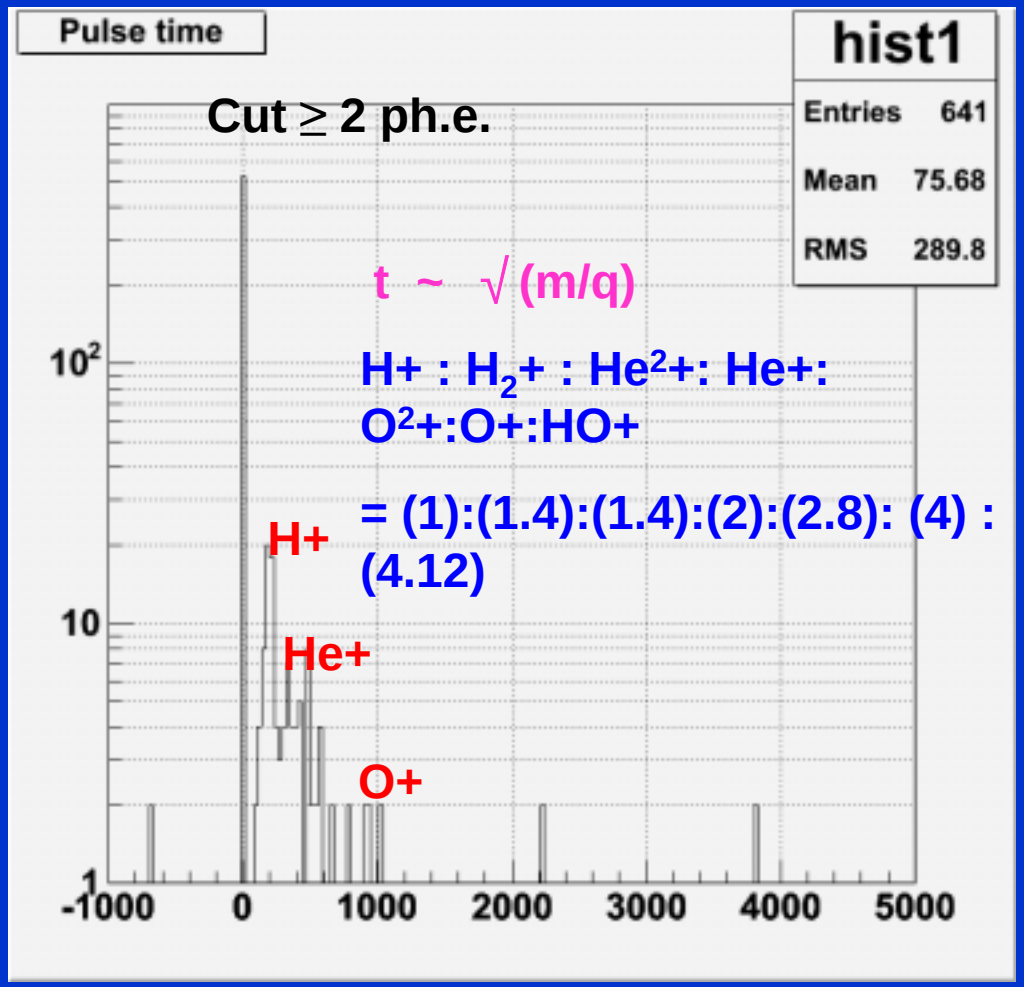
Afterpulsing setup

- Use pulse-generator to drive Laser. (10KHz)
- Use ET base.
- Time window for expected event : 5 μs.
- Measured by 2 GSample/s FADC.
- Illuminate with high/low light intensity.

Software Algorithm

- Find main pulses using the fixed time window method.
- Exclude main pulses, then calculate the pedestal and the pedestal RMS. Reject ADC counts larger than 3 sigma of pedestal RMS. Do one more iteration of calculation.
- Set small threshold on pulse height. Take data which are larger than (pedestal + threshold) as afterpulses. Find pulse maximum within 3 ns. Once find the maximum point, calculate the pulse area within +-1.5 ns (length of pulse ~ 3 ns).
- Apply cut on the pulse area.

Time Spectrum of Afterpulses



The time between the main pulse and the afterpulse is ~ to the transit time of the ion from the 1st dynode to the cathode.

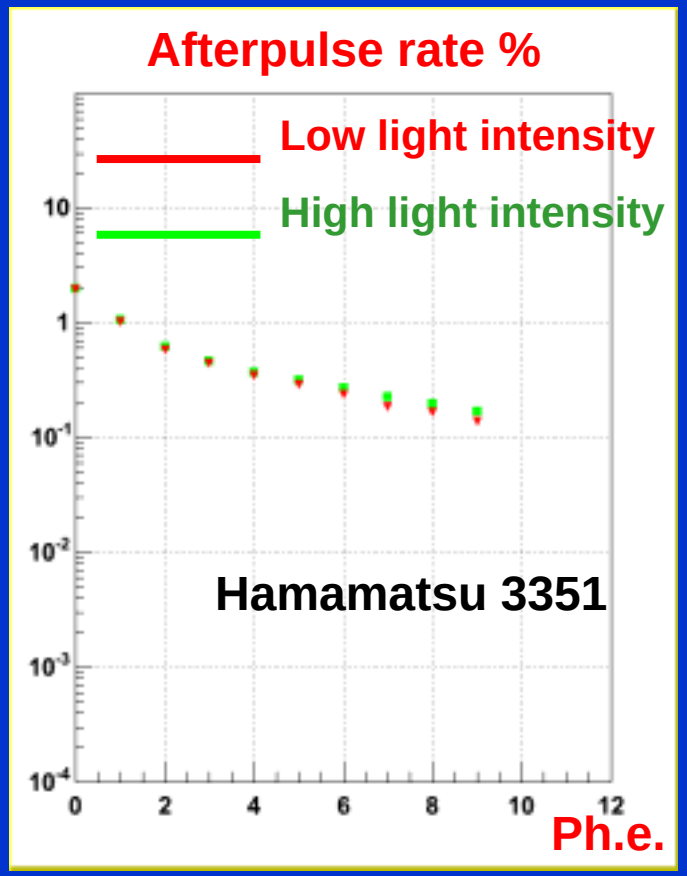
Assume the electric field between cathode and 1st dynode is E

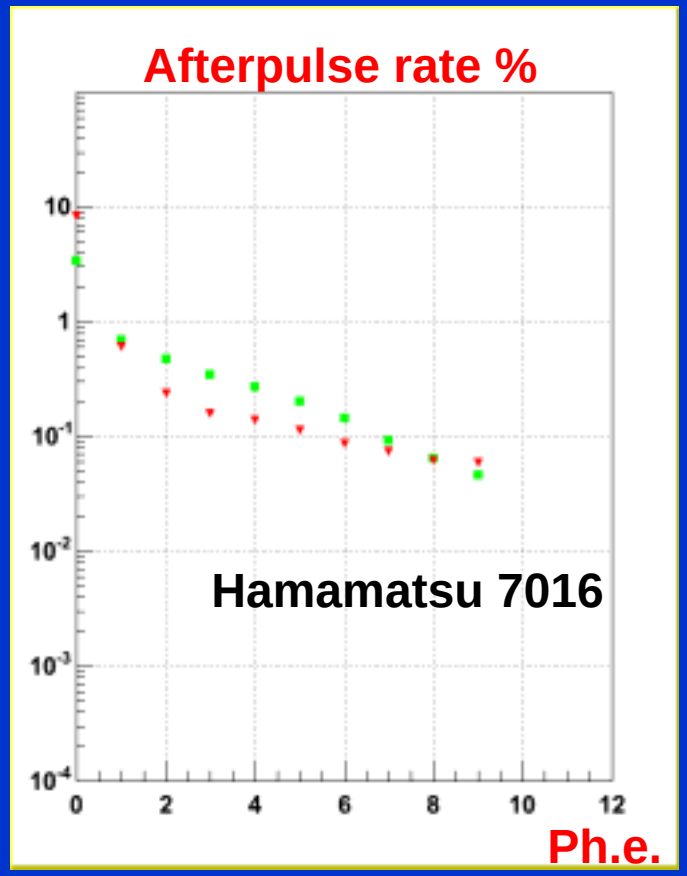
$q*E = m*a \quad a = q*E/m$

$S = 0.5*a*t^2;\ t^2 = 2*S/a$

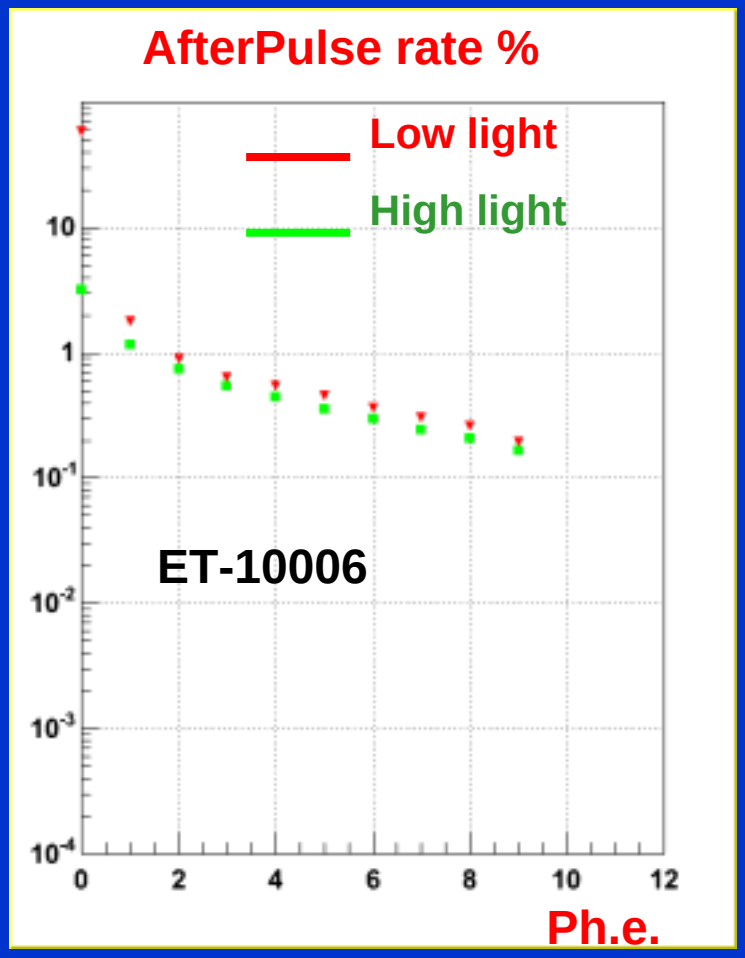
$t = \sqrt{2*S*m/(q*E)}$

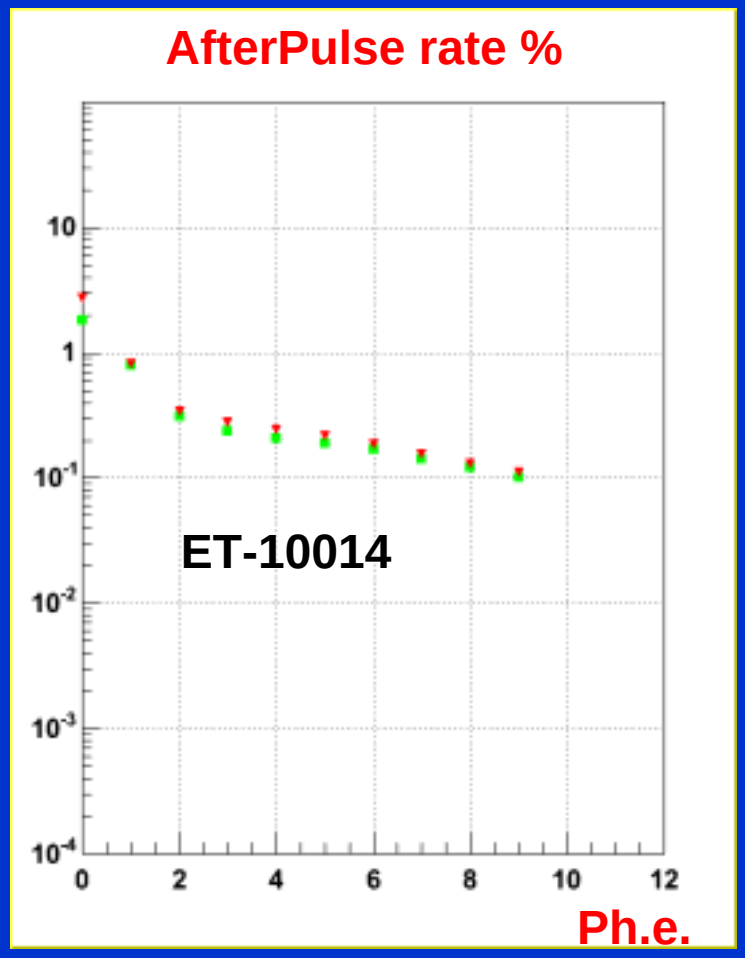
Afterpulse rate = $N_{\_afterpulse} / \{N_{\_main\text{-}pulses} \times M_{\_ph.e./pulse}\}$



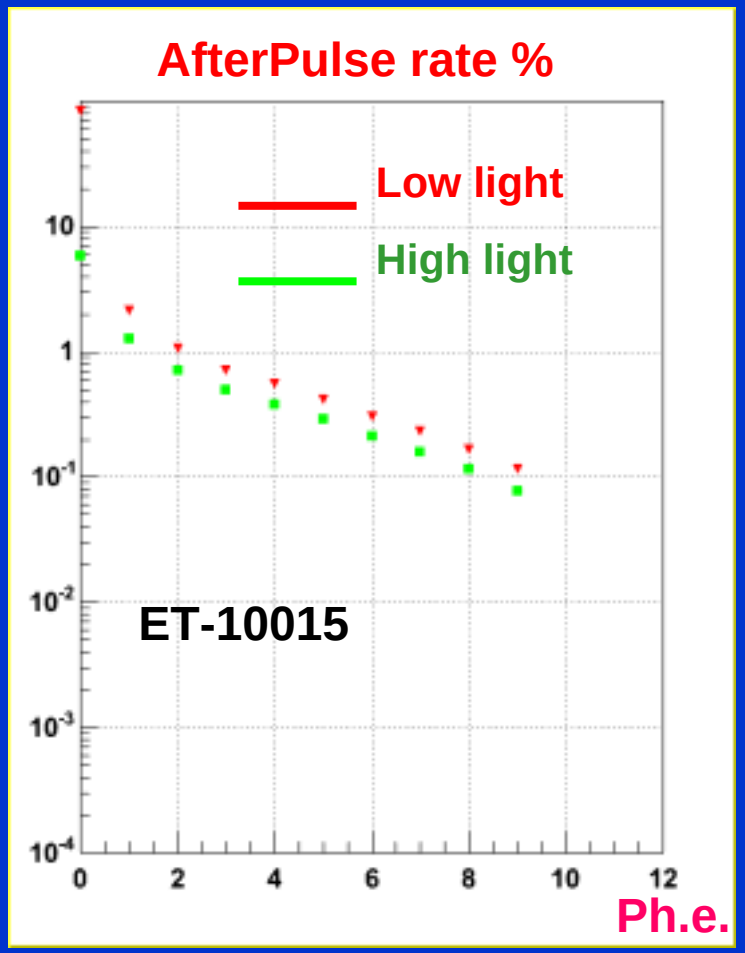


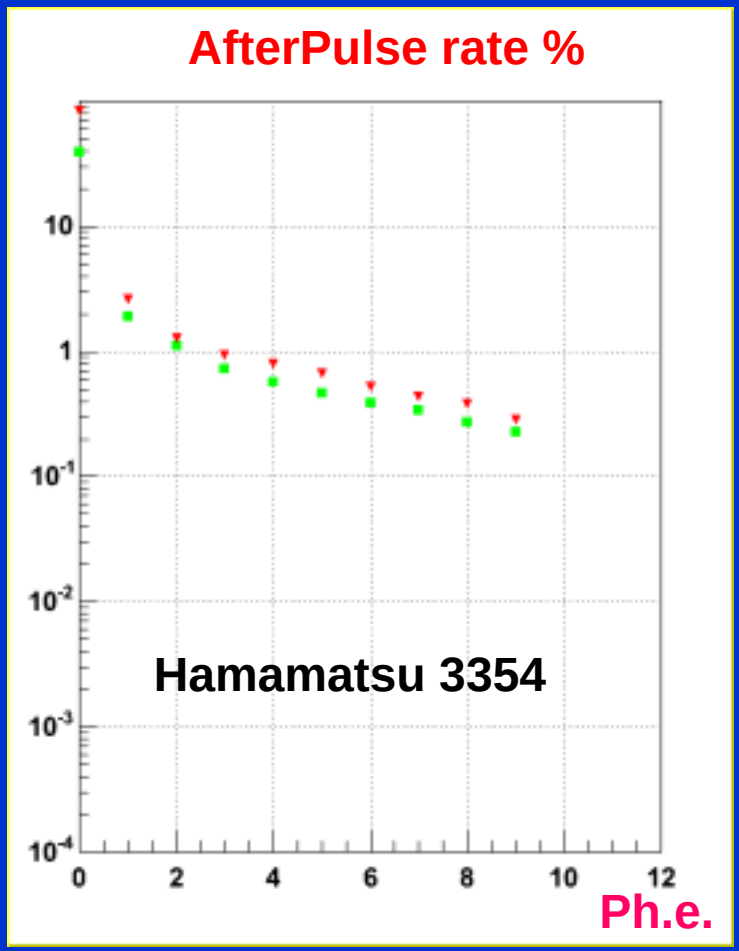
Afterpulsing



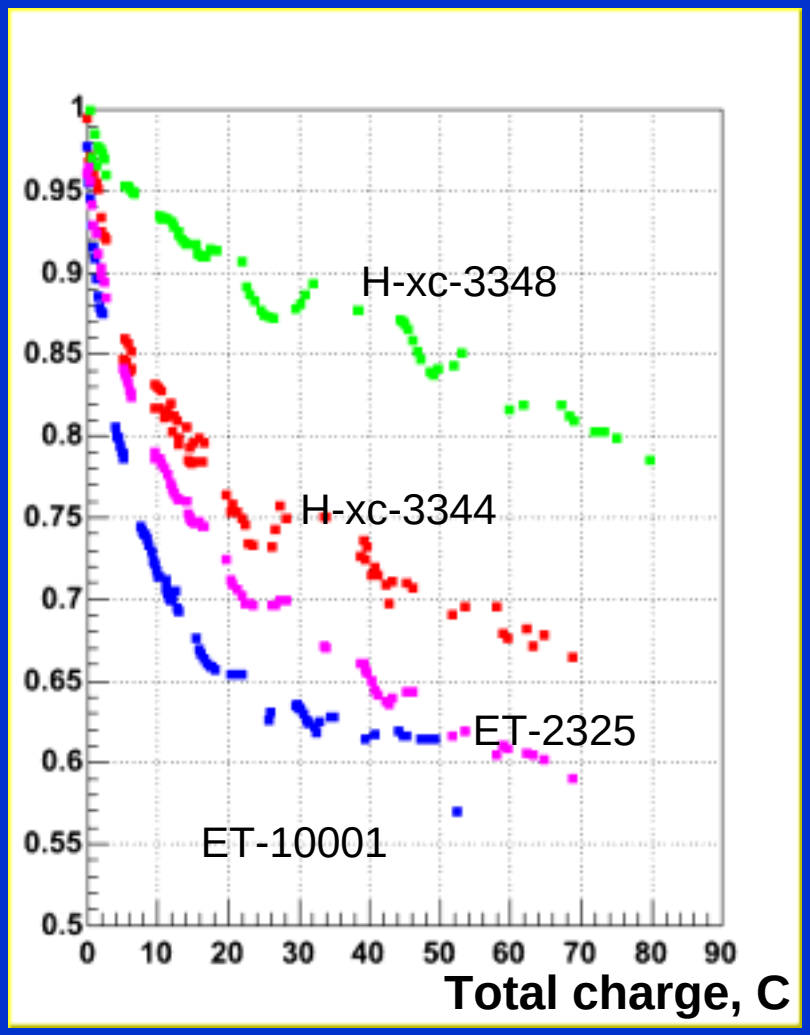


Afterpulsing



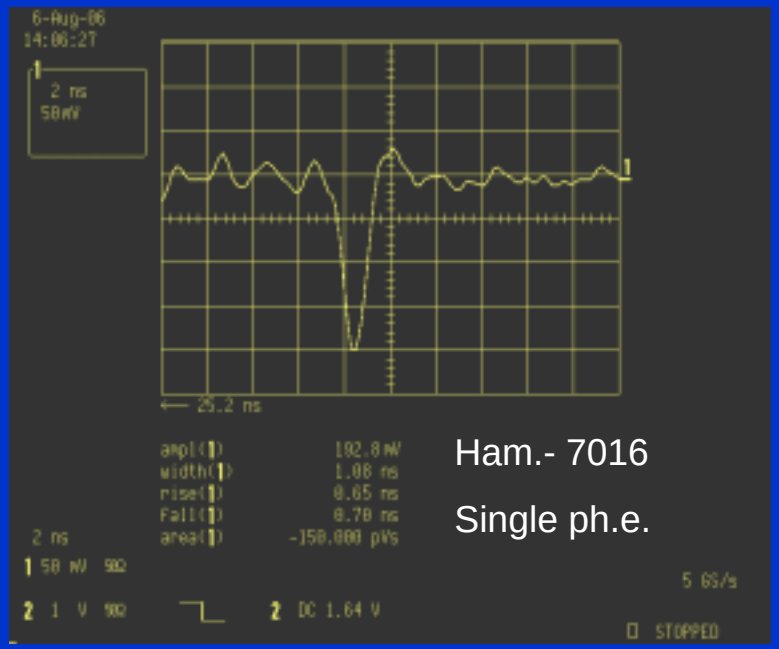


Ageing, pulse shape and timing



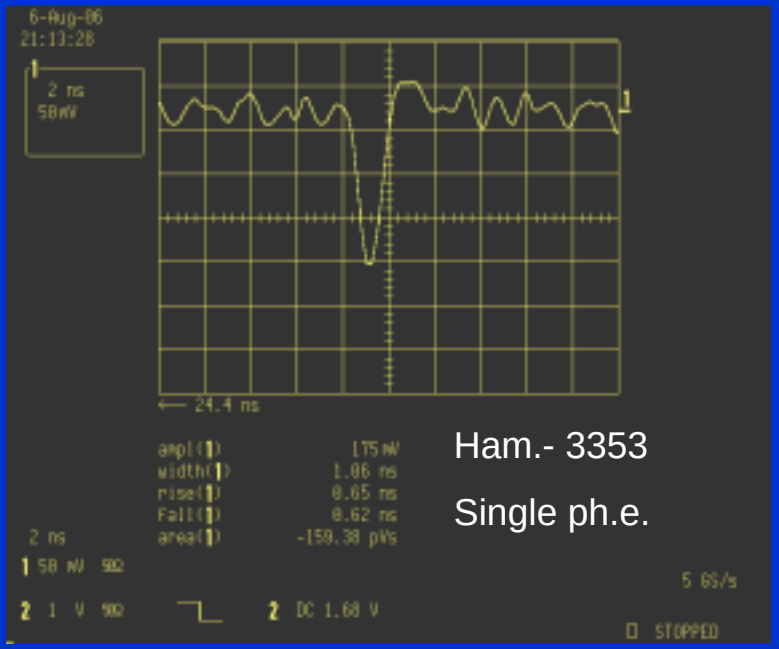
- The PMTs were run for a tota of 10150 minutes (7 days), under the constant Illumination that induced an initial anode current of 150 μA.

- Illumination changes (stability are taken into account by usin a monitoring PIN diode.



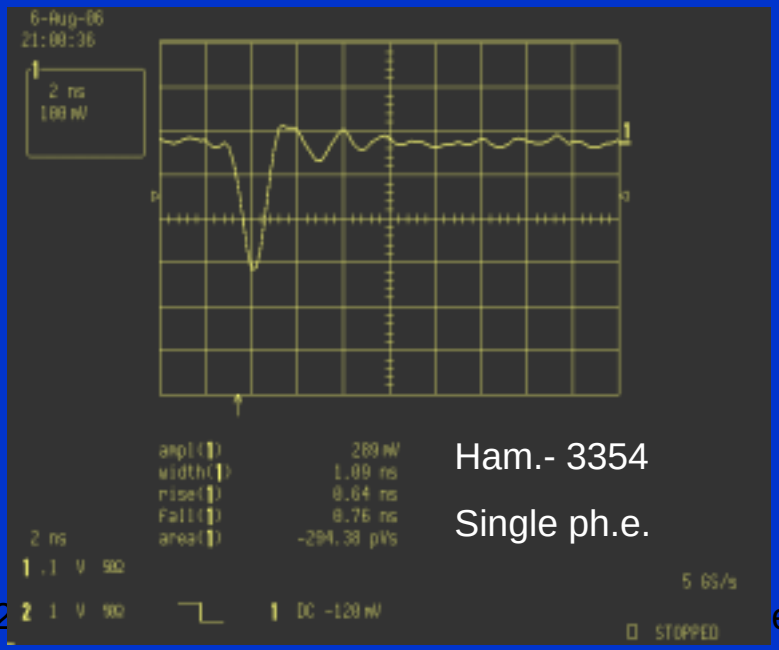
Ham.- 7016

Single ph.e.



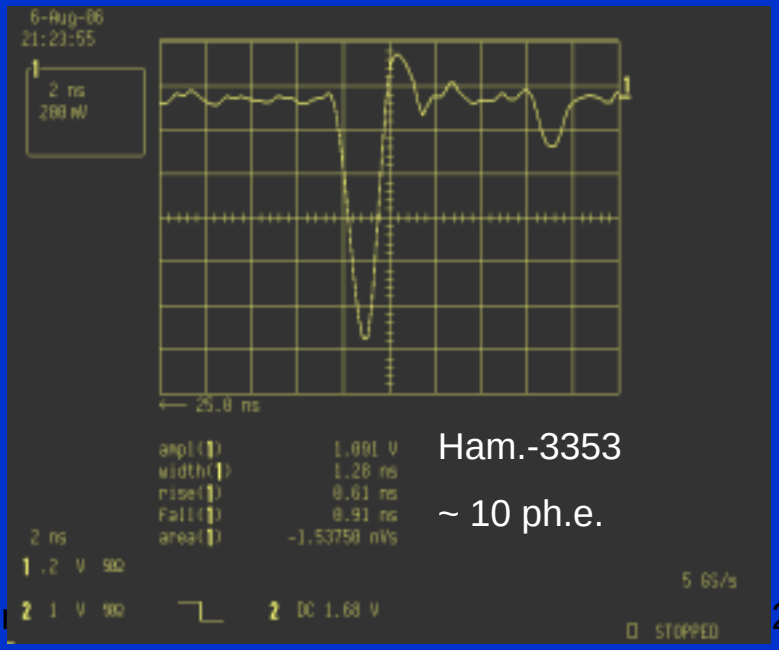
Ham.- 3353

Single ph.e.



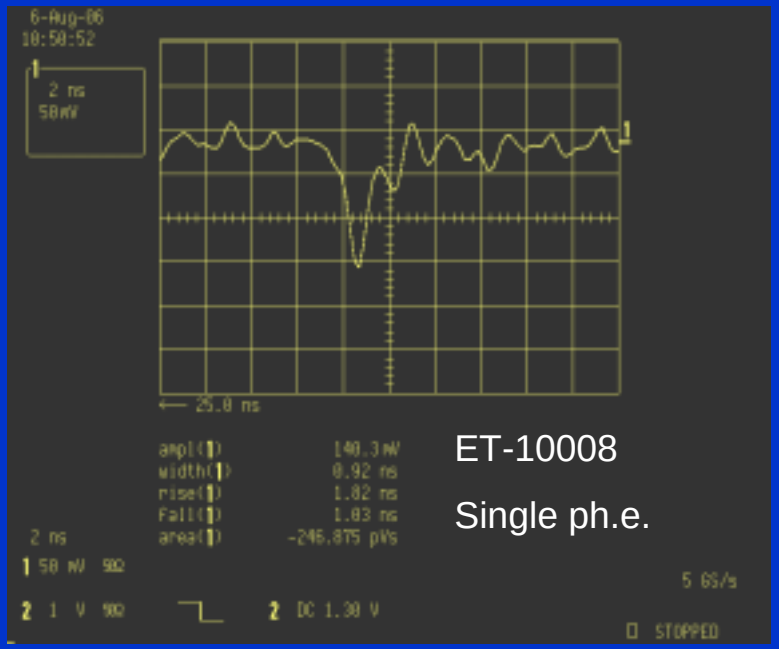
Ham.- 3354

Single ph.e.



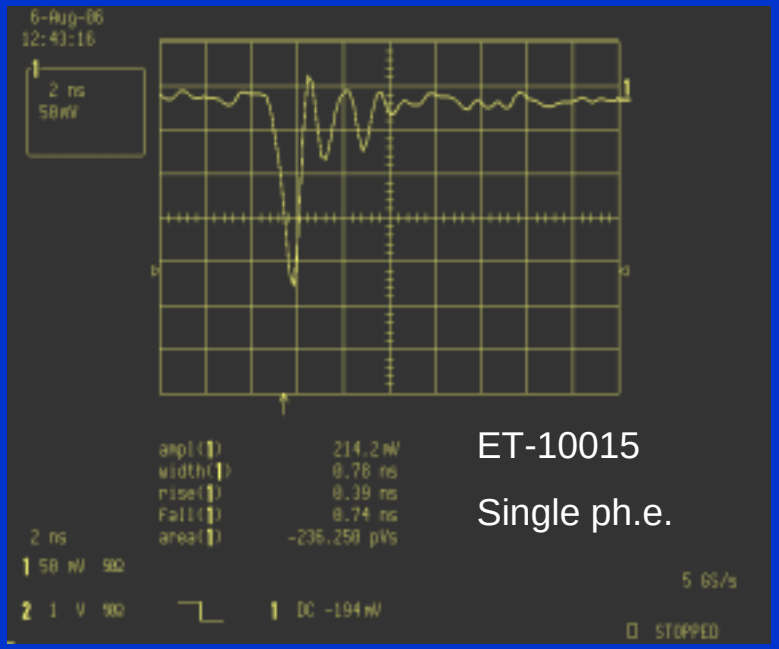
Ham.-3353

~ 10 ph.e.



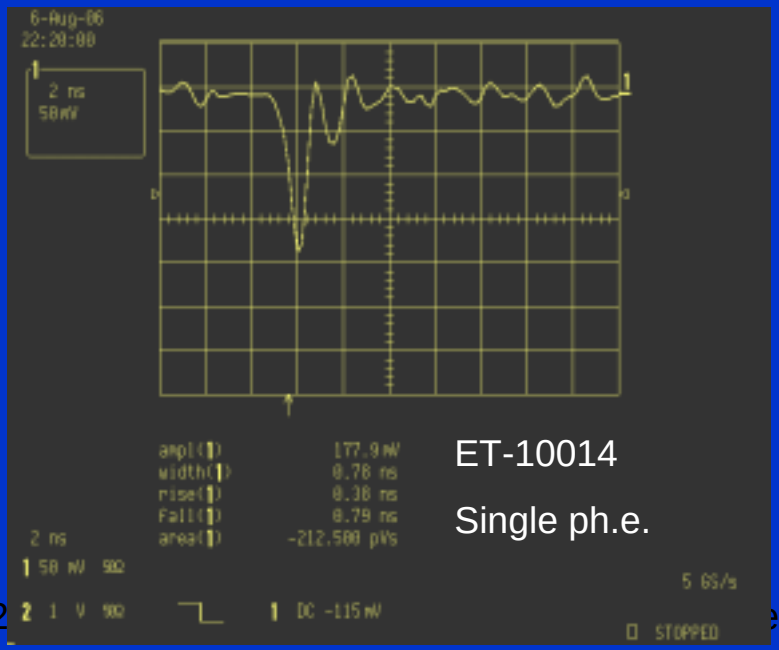
ET-10008

Single ph.e.



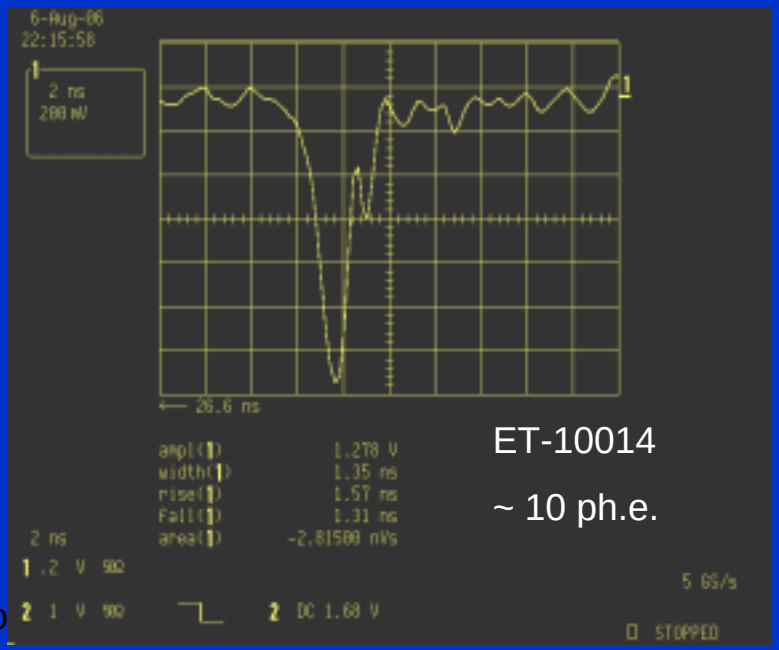
ET-10015

Single ph.e.



ET-10014

Single ph.e.

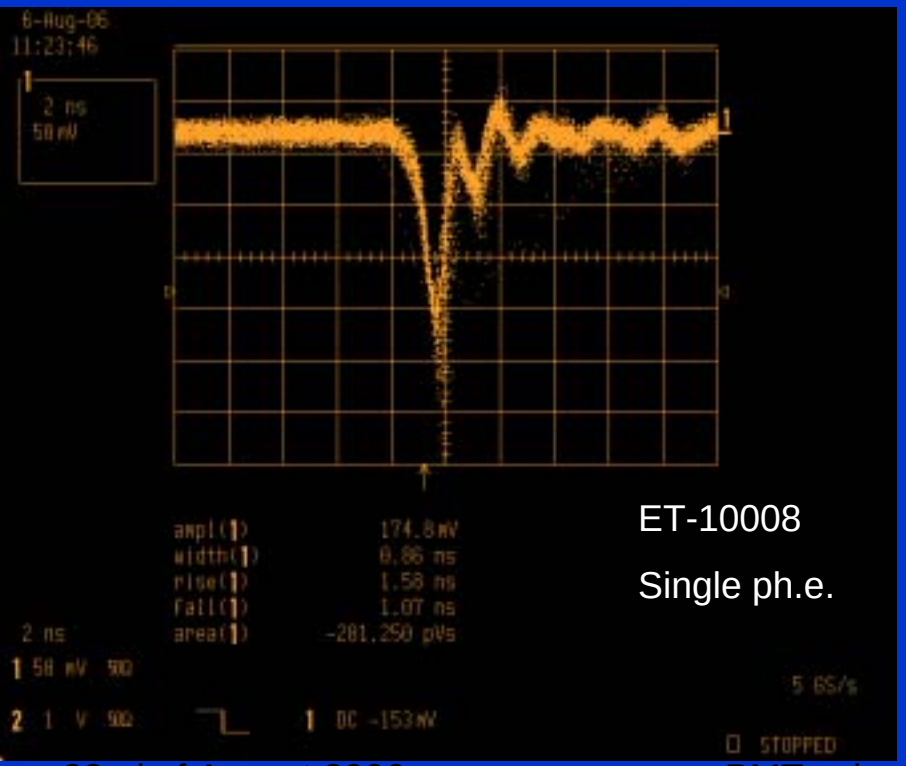


ET-10014

~ 10 ph.e.

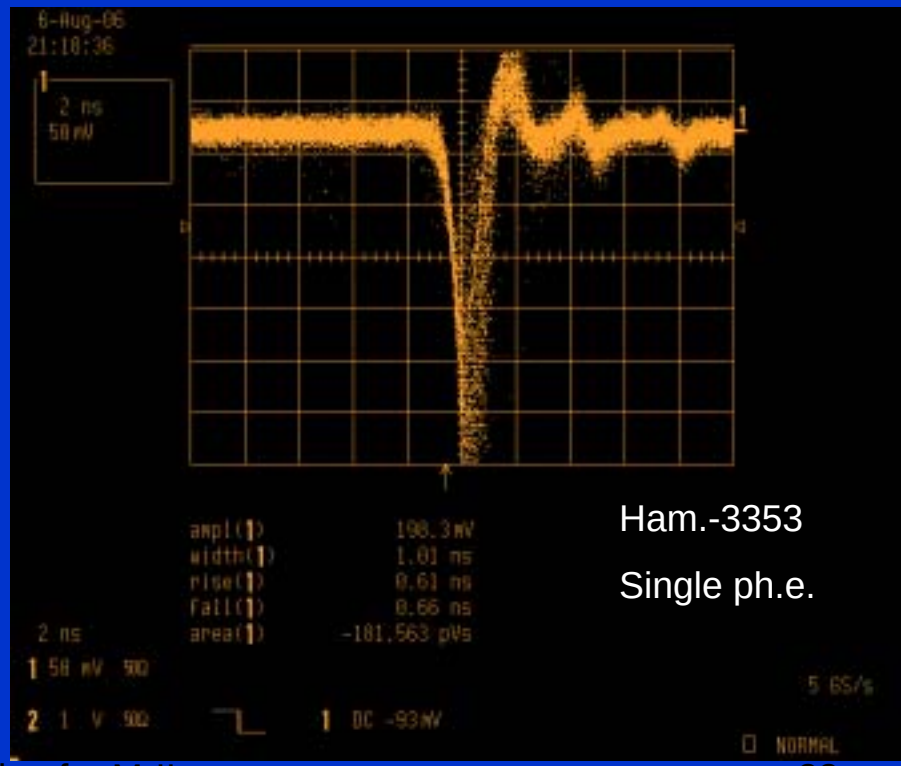
Transit time spread (TTS)

An ultra-fast oscillograph (1.5 GHz bandwidth), followed by a 2 GHz bandwidth amplifier (gain x 100) is used in pulse persistence mode; many pulses are overlayed on top of each other. The „thickness“ of the rising edge is < 400 ps for both types of PMTs.



ET-10008

Single ph.e.



Ham.-3353

Single ph.e.

Proposal for the supply of ETL Pmts
Type 9116WA (RbCs)
to the Max Planck Institute for the MAGIC 2 Telescope

August 17, 2006

Electrical Specification (using 2R, R.....R divider) – 9116WA (KCs)

	Unit	Min	Typical	Max
Photocathode: KCs Bialkali				
quantum efficiency at peak (ca 330nm)	%	27.0	31.0	
quantum efficiency at 300nm			30.0	
quantum efficiency at 530nm)			8.0	
CB sensitivity	uA/blue Lm		12.2	
Afterpulses (see note 1)				
Total rate (>2 pe)	%		5	
>4 pe	%		2	
Dynodes: 6 CF high stability CsSb				
anode sensitivity at 900V	A/Lm	0.4	1.5	7.5
first dynode gain (see note 1)			7.5	
Timing (see note 1)				
single electron rise time	ns		1.8	
single electron fall time	ns		4.0	
single electron fwhm	ns		3.1	
single electron time spread (sigma)	ns		0.5	
Resolution (see note 1)				
single p.e. resolution	P/V ratio	1.0:1	1.3:1	
Collection efficiency	%		92	
Maximum Ratings				
anode current	uA		100	
cathode current	nA		30	
Gain	$x10^6$			0.06
anode sensitivity	A/lm			5
Temperature	degrees C	-30		60
V(k-a) (subject to max A/Lm)	V			1800
V(k-d1)	V			400
V(d-d) (subject to max V(k-a)	V			200
Long term gain stability				
Total charge for gain reduction by 50%	Coulombs		250	
Temperature coefficients				
Gain	%/deg C		-0.2	
quantum efficiency (at 400nm)	%/deg C		-0.2	

9116WA (KCs) for MPI, Issue 1.1 - August 2006

electron tubes

Mechanical Specification

	Unit	Min	Typical	Max
Diameter	mm	24.4	24.9	25.4
Overall length (excluding pins)	mm	39.0	41.0	43.0
Weight	g		15	
Glass window UV transmission (50%)	nm	220		

Note 1:
The above specifications relate to the standard ETL test methods using a voltage divider of 2R, 1R.....1R. The same parameters measured on MPI's dedicated equipment normally give better results for these parameters.

Pricing Proposal

A single unit price of: 249- Euros each nett FOB UK based on:-

Total quantity: 1300 of pmt Type 9116WA

To meet above specifications with approximately 750 pmts having a peak quantum efficiency of 30% or greater and approximately 300 pmts with 32% or greater.

The peak wavelength of the KCs cathode pmt is very to close to the peak of the Cerenkov emission spectrum.

Time Scale

Deliveries to be completed within 9 calendar months from receipt of order.

Contractual Terms

Payment terms: net 30 days
Validity of quotation: 30days
Otherwise subject to ETL standard terms and conditions.

Related Offers

Please see the ETL offer, also of 7 August, for the 9116WA (RbCs) alternative pmt and the offer for corresponding power bases.

If the full quantities of both pmts and power bases are ordered from ETL at the same time, a discount of 5% will apply to the total value of the combined orders.

Please also see attached additional options.

MPI pmt 9116 – proposal for MAGIC 2
Ron Stubberfield, Andy Cormack

Proposal for the supply of ETL Pmts
Type 9116WA (RbCs)
to the Max Planck Institute for the MAGIC 2 Telescope

August 17, 2006

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	Unit	Min	Typical	Max
Photocathode: RbCs (bialkali)				
quantum efficiency at peak (ca 330nm)	%	24.0	26.0	
quantum efficiency at 300nm			22.0	
quantum efficiency at 530nm)			12.0	
CB sensitivity	uA/blue Lm		11.7	
Afterpulses (see note 1)				
Total rate (>2 pe)	%		5	
>4 pe	%		2	
Dynodes: 6 CF high stability CsSb				
Anode sensitivity at 1000V	A/Lm	0.6	2.0	6.5
first dynode gain (see note 1)			7.5	
Timing (see note 1)				
Single electron rise time	ns		1.8	
Single electron fall time	ns		4.0	
Single electron fwhm	ns		3.1	
Single electron time spread (sigma)	ns		0.5	
Resolution (see note 1)				
Single p.e. resolution	P/V ratio	1.0:1	1.3:1	
Collection efficiency	%		92	
Maximum Ratings				
Anode current	uA		100	
cathode current	nA		30	
Gain	$x10^6$			0.06
Anode sensitivity	A/lm			5
Temperature	degrees C	-30		60
V(k-a) (subject to max A/Lm)	V			1800
V(k-d1)	V			400
V(d-d) (subject to max V(k-a)	V			200
Long term gain stability				
Total charge for gain reduction by 50%	Coulombs		250	
Temperature coefficients				
Gain	%/deg C		-0.2	
quantum efficiency (at 400nm)	%/deg C		-0.2	

9116WA (RbCs) for MPI, Issue 1.1 - August 2006

electron tubes

Mechanical Specification

	Unit	Min	Typical	Max
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Glass window UV transmission (50%)	nm	220		

Note1:
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Pricing Proposal

A single unit price of: 352,- Euros each nett FOB UK based on :-

Total quantity: 1300 of pmt Type 9116WA (RbCs)

The RbCs cathode pmt is the type used for MAGIC 1 and is optimised for blue/green sensitivity, with a relatively wide spectral response curve. The corresponding CB value for the lower limit QE is 10.75, compared to a minimum of 9.0 for MAGIC 1.

Time Scale

Deliveries to be complete within 9 calendar months from receipt of order.

Contractual Terms

Payment terms: net 30 days
Validity of quotation: 30days
Otherwise subject to ETL standard terms and conditions.

Related Offers

Please see the ETL offer, also of 7 August, for the 9116WA (KCs) alternative pmt and the offer for corresponding power bases.

If the full quantities of pmts and power bases are ordered from ETL at the same time, a discount of 5% will apply to the total value of the combined orders.

Please also see attached additional options.

MPI pmt 9116 – proposal for MAGIC 2
Ron Stubberfield, Andy Cormack

9116W for MPI – Additional Options Iss 1.0

Revised and extended offer:-

In response to your request, we have amended our offer for pmts for MAGIC 2 to include minimum SER limits. We have also extended the cathode sensitivity options, with particular reference to your proposal to identify the best pmts for certain parts of the camera.

In the course of carrying out the data analysis for these revisions, we updated our electron-optics simulations, which show that the collection efficiency is typically 92% and not 80% as previously stated. This should be useful to you for estimating effective quantum efficiency.

We believe that the cathode sensitivity options, combined with the above referred to high collection efficiency, will provide a very competitive effective quantum efficiency performance capability for both the KCs and the RbCs versions.

The relative merits of the KCs and RbCs cathodes are best assessed by folding-in the detected light spectrum, which we assume you have done based on the your measurements of the samples we supplied. Please advise if you need individual spectral response curves from us.

With regard to SER, we are not able to achieve the minimum of 1.5:1which you requested but we guarantee that all pmts will have a resolvable SER and our offer includes options for a minimum figure of 1.1:1 (compared to 1.0:1 for MAGIC 1).

Attached are new issues (1.1) of the previous 2 offers for the two cathode types, one of which meets your request for minimum 27% peak QE. The minimum SER of 1.0:1 (as MAGIC 1) and the updated collection efficiency have been added and the prices are unchanged.

Updated versions (now iss1.1) of the original quotations are attached.

Extended Options

In addition to these amended offers, we are offering the following additional options for 9116W pmts, based on various CB limits:-

a) Additional options for all 1300 pmts meeting one specification:-

Version	Min CB	Typ CB	Min SER	Typ SER	Price (Euros)
RbCs	10.75	12.0	1.0	1.30	375.0
RbCs	11.00	12.0	1.0	1.30	397.0
KCs	10.00	11.5	1.0	1.30	248.0
KCs	10.30	11.5	1.1	1.35	288.0
KCs	10.50	11.5	1.2	1.40	390.0

9116W for MPI – Additional Options Iss 1.0

b) Additional options for 800+500 pmts meeting two specifications:-

Version	Best 800		Remaining 500		All 1300		Price
	Min CB	Typ CB	Min CB	Typ CB	Min SER	Typ SER	(Euros)
RbCs	11.0	12.0	9.5	10.5	1.1	1.3	338.0
	11.2	12.0	10.0	10.7	1.1	1.3	357.0
KCs	11.4	12.0	9.5	11.0	1.1	1.3	254.0
	11.4	12.0	10.0	11.1	1.1	1.3	260.0
	11.5	12.0	10.5	11.2	1.1	1.3	272.0
	11.6	12.0	11.0	11.3	1.1	1.3	303.0

Notes:-

1) Peak QE (at ca 410nm) for RbCs version is approximately CB * 2.36
2) Peak QE (at ca 330nm) for KCs version is approximately CB * 2.69
3) Typical QE at 530nm for RbCs version is 12%
4) Typical QE at 530nm for RbCs version is 8%
5) Discount TBD for combined orders for pmts and power bases in relation to the extended options in a) and b).
6) All prices are nett FOB UK. Please refer to original quotation/specifications for all other terms and conditions.

R A Stubberfield 17 August 2006

MPI pmt 9116 – proposal for MAGIC 2
Ron Stubberfield, Andy Cormack

TECHNICAL

DEPT #22
Aug 2006

PHOTOMULTIPLIER TUBE R10408 (for MAGIC II)

25 mm (1 Inch) Diameter, Hemispherical Window
Low Profile, Wide solid Angle,
Bialkali Photocathode, 6 stage, Head-on Type

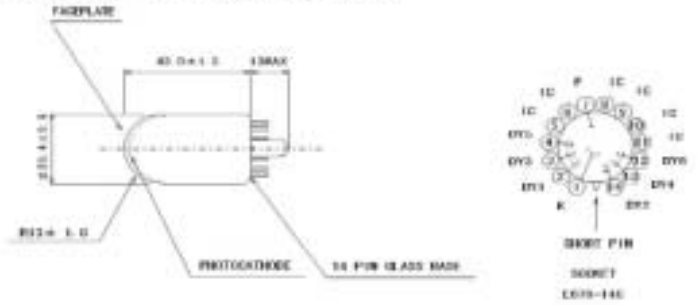
GENERAL

Parameter		Description	unit
Spectral Response		185 to 650	nm
Wavelength of Maximum Response		420	nm
Photocathode	Material	Bialkali	-
	Minimum Effective Area	26 Solid (R13)	-
Window Material		UV glass	-
Dynode	Structure	Linear focused	-
	Number of stages	6	-
	Material	Bialkali	-
Ambient Temperature	Storage	-80 to +50	°C
	Operating	-30 to +50	
Base		14 pin Glass Base	-
Suitable Socket		Option (E678-14C)	-

MAXIMUM RATING (Absolute Maximum values)

Parameter		Value	Unit
Supply voltage	Between Anode and Cathode	1250	V
	Between Anode and Last Dynode	250	V
Average Anode Current		0.1	mA

DIMENSIONAL OUTLINE AND BASING DIAGRAM



UNIT: mm

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PHOTOMULTIPLIER TUBE R10408

CHARACTERISTICS (at 25 °C) with Standard Voltage Divider

Parameter			Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2854 K)		60	90	-	μA/lm
	Quantum Efficiency	380 nm	-	12	-	%
		Peak	27	30	-	
		530 nm	-	18	-	
	Blue (CS 5-58 filter)	index	-	11.0	-	-
Anode Sensitivity	Luminous (2854 K)		-	5.6	-	A/lm
GAIN			1×10^6	4×10^7	1×10^8	-
	First Dynode (K-Dy1: at 210 V)		-	9	-	-
Single p.e. Resolution (FWHM)			-	120	-	%
Peak / Valley ratio (single p.e.)			1.2	1.5	-	-
Collection Efficiency			-	85	-	%
Anode Sensitivity Temperature Coefficient (PC)			-	-0.4	-	%/°C
Anode Dark Current (after 30 min. storage in darkness)			-	1	10	nA
After Pulse rate (more than 4 p.e.)			-	-	3.0	%
Time Response	Anode Pulse Rise time		-	2.4	-	ns
	Anode Pulse Fall time		-	2.7		
	Anode Pulse FWHM		-	2.7	-	
	Transit Time			22		
Gain Reduction at 50 %			360	-	-	C

NOTE: Anode characteristics are measured with a voltage distribution ratio shown below:

Standard Voltage Divider and Supply Voltage

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	P
Ratio	2	1	1	1	1	1	1	1

Supply Voltage: 850 V, K: Cathode, Dy: Dynode, P: Anode

Offer : 222.-EUR/PMT

ENVIRONMENTAL TESTING

Shock:
1000 m/s² (100 g's), 11 ± 1 ms 3 impact shocks per axis

Vibration:
200 m/s² (20 g's), 50 to 2000 Hz 90 min. total 1 sweep per axis

*note: Only initial production tubes are tested for these shock and sine vibration tests.

Notes: The material in the PhotoMultiplier Tube contains beryllium and lead. Please follow the applicable regulations regarding disposal of hazardous materials and industrial wastes in your country, state, region or province.

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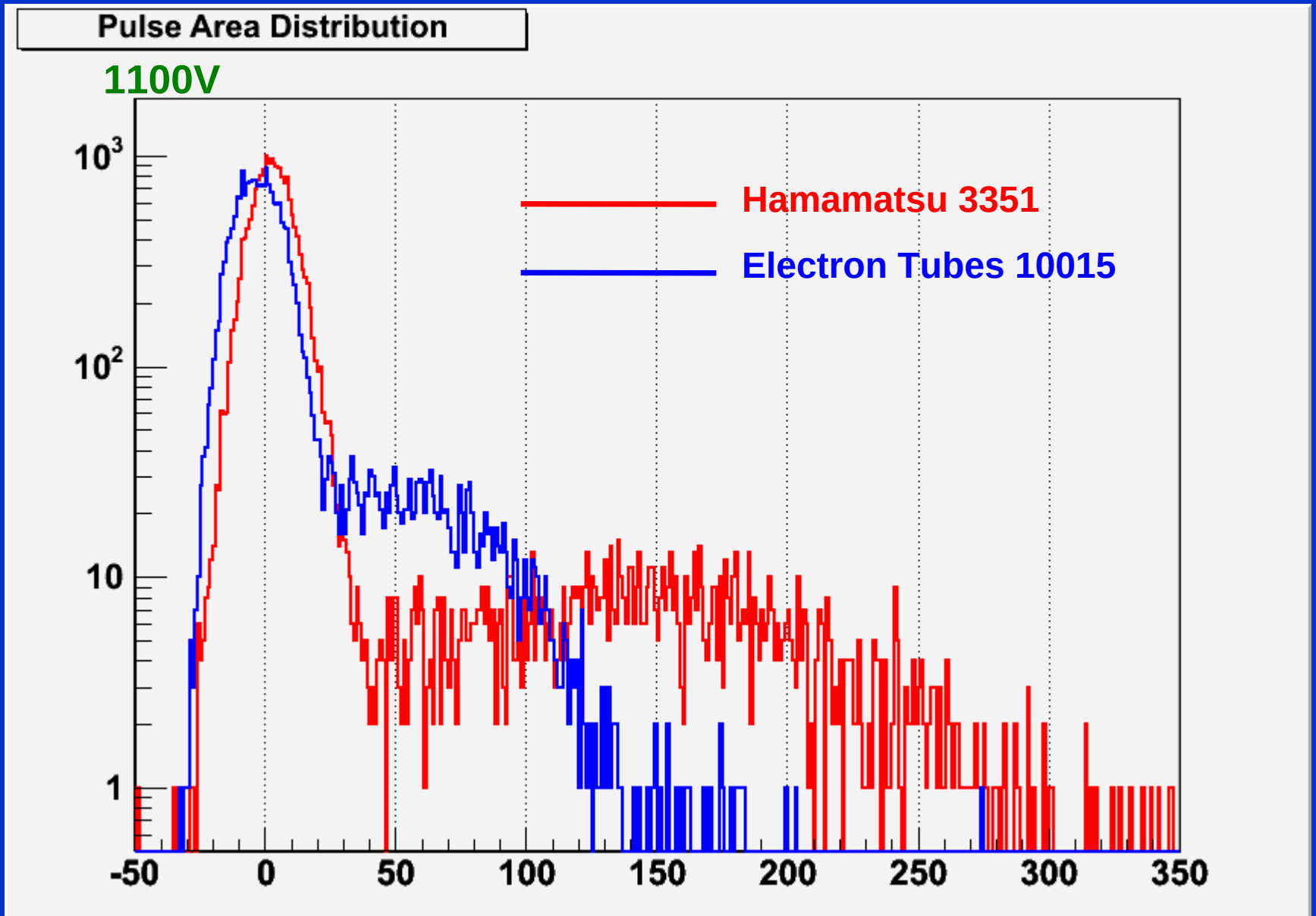
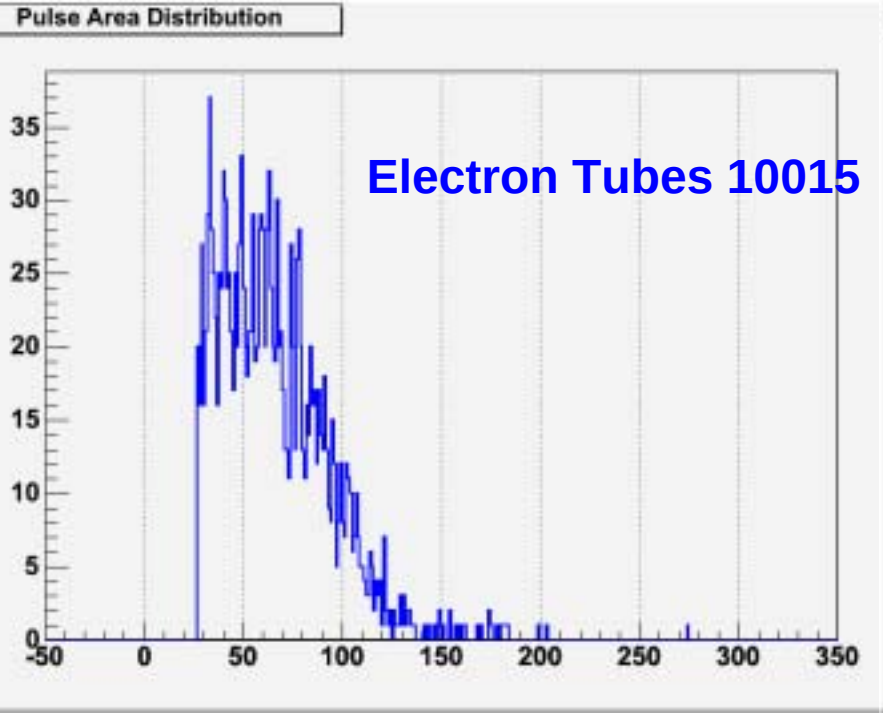
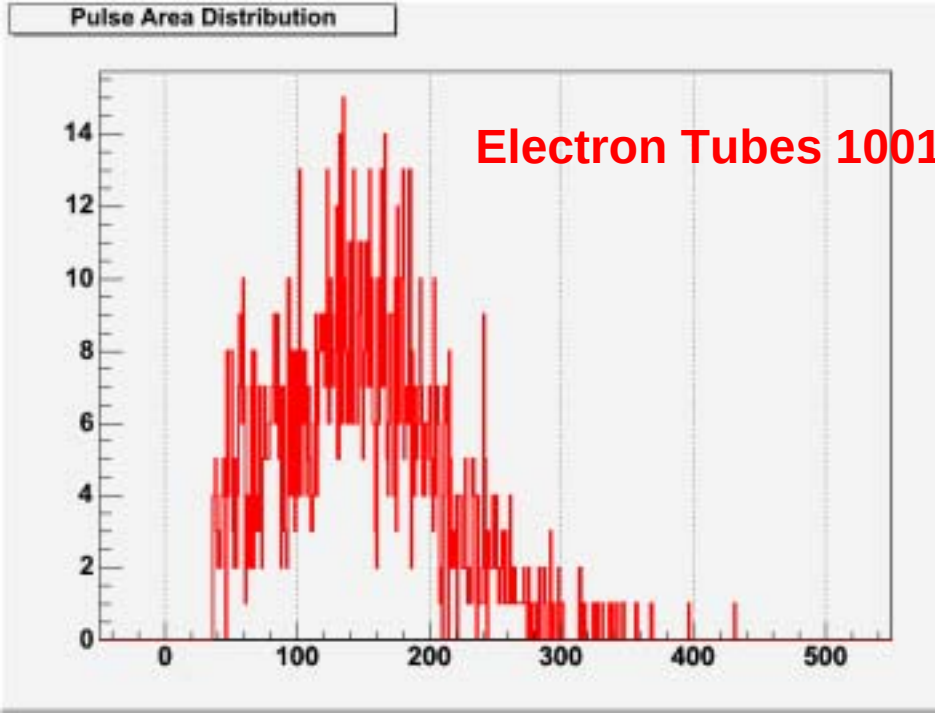
Back Up Slides

Photoelectron collection efficiency.







1100V

Sigma	**27.69**	**61.62**
Total area	**110072**	**196922**
Mean	**66.26**	**147.507**
# of entry	**1611**	**1335**

1200 V	ET10015	HAMAMATSU 3351
Sigma	44.08	81.49
Total Area	184254	305948
Mean	89.96	182.54
# of Entry	2048	1676

1400 V	ET10015	HAMAMATSU 3351
Sigma	84.85	154.11
Total Area	371668	446003
Mean	165.923	315.19
# of Entry	2240	1815